CHAPTER 17

HEAT

Heat has been said to be a form of energy. All matter in its normal state contains heat to some degree, this heat being generated by the movement of molecules and electrons within the matter. Heat is often referred to as the internal energy of a body. Energy, in the form of heat, may be absorbed by or extracted from a body by an external source. There are many ways this may occur. The most simple example is when a piece of metal is left lying in the sun. This metal becomes 'hot'. What really happens is the metal absorbs energy from the sun, because the sun is at a higher temperature than the metal. If the metal is moved away from the sun's influence, it will become 'cool'. In the process of decreasing in temperature, the metal has given up energy to the surrounding atmosphere.

Energy may be converted from one form to another form. Mechanical energy is converted to heat energy when there is friction between metal surfaces. The kinetic energy stored in a moving vehicle is converted to heat at the tyres and brakes when the vehicle is stopping. Electrical energy (E I t) is deliberately converted to heat in such appliances as electric ranges, radiators, ovens, etc. In this chapter the factors which determine the quantity of heat energy a body may absorb or release will be examined. In addition, a relationship between electrical energy and heat energy will be evolved, while examples of the efficiency of converting from electrical energy to heat energy will be solved.

17.1 FACTORS DETERMINING HEAT ENERGY (H)

(a) Mass

Heat is the result of the movement of molecules or electrons in a body. A large mass of a certain substance will always contain a larger number of molecules than a smaller mass of the same substance in the same state of matter. To raise a mass of a substance through a fixed temperature range (for example 10 degrees Celsius) each molecule in the substance must absorb a certain amount of energy. If a larger mass of the same substance is to have its temperature raised through the same range (10^{o}C), the extra molecules of the large mass must receive extra discrete amounts of energy for the temperature to rise through this range. From this it can be seen that the larger the body of a certain material the more energy it will contain at a given temperature. Heat is directly proportional to the mass of a body.

$$H \propto m$$

(b) Temperature

The base SI unit for temperature is degrees Kelvin. The Kelvin scale has its lower limit point at absolute zero (273^{o}C). The more common scale used for temperature measurement in the SI units is the Celsius scale. This scale has a lower fixed point of 0^{o}C and an upper fixed point of 100^{o}C. In calculations in this chapter that involve changes in temperature, the Celsius range will be applied. However because 1^{o}C change equals 1^{o}K change, the Kelvin scale could be used.

As stated previously, a mass of a material requires a certain amount of energy to raise its temperature from one point to another. If, after reaching the higher point, the application of heat to the material is continued, the molecules within the material will increase their movement or agitation. This increase in movement means an increase in energy within the material. The greater the temperature change due to heat in a material, the higher is the quantity of energy in the material. Heat is directly proportional to the temperature change.

$$H \propto t_c$$

where t_c is the change in temperature from the initial temperature to the final temperature.

(c) Type of Material

The quantity of heat absorbed by a material, for a fixed temperature change, depends on the chemical structure of the material. Heat flow is much the same as electric current flow. Good electrical conductors are usually good heat conductors or absorbers while electrical insulators are usually good heat insulators. The ability of a material to accept heat is known as its absolute specific heat capacity with units of joules per kilogram per degree Kelvin (J kg^{-1} K^{-1}). The absolute specific heat capacity of a material consists of two components -

(1) The specific heat capacity of water, which is the heat required to raise one gramme of water through one degree centigrade and is equal to –

$$4.18 \times 10^{3} \ \mathrm{J\ kg^{-1}\ K^{-1}}$$

(2) The relative specific heat capacity of the material (C_r) which is the heat required to raise one gramme of that material through the same temperature range.

The relative specific heat capacities of some of the materials used in the electrical field are listed in Table 17.1

Table 17.1

MATERIAL	RELATIVE SPECIFIC HEAT CAPACITY
Water	1
Brass	0.094
Aluminium	0.215
Nickel Chrome Alloys	0.106 – 0.112
Copper	0.092
Silver	0.056
Lead	0.031

17.2 CALCULATION OF HEAT ENERGY

The quantity of energy a body takes in or gives out is proportional to the mass and material of the body and the temperature change in the body.

$$H = m\ C\ t_c$$

or $$H = m\ C_o\ C_r\ (t_f - t_i)$$

Where –

H = energy in joules

m = mass in kilograms

C_o = 4.18×10^{3} joules per kilogram per degree Kelvin

C_r = relative specific heat of the material

t_f = final temperature in degrees Celsius

t_i = initial temperature in degrees Celsius

Example 17.1

Determine the energy required to heat a mass of 2000 grams of copper from 20°C to 100°C.

$$m = \frac{2000}{1000} = 2\ \mathrm{kg}$$

$C_o = 4.18 \times 10^{3}\ \mathrm{J\ kg^{-1}\ K^{-1}}$

$C_r = 0.092$

$t_f = 100^{\circ}\mathrm{C}$

$t_i = 20^{\circ}\mathrm{C}$

$H = ?$

$H = m\ C_o\ C_r\ (t_f - t_i)$

$= 2 \times 4.18 \times 10^{3} \times 0.092\ (100 - 20)$

$= 2 \times 4.18 \times 10^{3} \times 0.092 \times 80$

= 61529 joules

= 61.529 kJ

Example 17.2

How much energy would be required to boil 2 litres of water if the initial temperature of the water was 20°C.

$m = 2kg$

$C_c = 4.18 \times 10^3$

$C_r = 1$

$(t_f - t_c) = 80^oC$

$H = ?$

$H = M\ C_o\ C_r\ (t_f - t_c)$

$2 \times 4.18 \times 10^3 \times 1 \times 80$

$= 668800J$

$= 668.8\ kJ$

17.3 HEATING EFFICIENCY

Losses occur whenever one form of energy is converted to another form of energy. When energy from an electrical source ($E\ I\ t$) is converted to heat energy ($m\ C_o\ C_r\ (t_f - t_i)$), and this heat energy used to raise the temperature of a material, losses occur due to radiation of the heat to the surroundings. The efficiency of the heating process is calculated from the ratio of output energy to input energy.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$\eta = \frac{\text{output}}{\text{input}} \times 100$$

$$= \frac{(m\ C_o\ C_r\ (t_f - t_i))}{E\ I\ t} \times 100$$

Example 17.3

An electric jug containing 1500 c.c. of water, when connected to 240 volts draws 7.5 amperes from the supply for 6 minutes. Calculate the efficiency of the jug if the temperature of the water is raised from 20°C to boiling point of 100°C.

$E = 240V$

$I = 7.5\ A$

$t = 6 \times 60 = 360s$

$m = 1500\ c.c. = 1.5\ kg$

$C_o = 4.18 \times 10^3\ J\ kg^{-1}\ K$

$C_r = 1$

$t_f = 100^oC$

$t_i = 20^oC$

$$\eta = \frac{m\ C_o . C_r\ (t_f - t_i)}{E\ I\ t} \times 100$$

$$= \frac{1.5 \times 4.18 \times 10^3 \times 1\ (100 - 20)}{240 \times 7.5 \times 360} \times 100$$

$$= \frac{1.5 \times 4.18 \times 10^3 \times 80 \times 100}{240 \times 7.5 \times 360}$$

$= 77.4\%$

Example 17.4

An electric urn containing 3 litres of water draws 5 amperes from a 240 volt supply as it raises the temperature of the water from 20^oC to 80^oC. If the urn is 80% efficient calculate the time required to heat the water.

$m = 3\text{ kg}$

$C_o = 4.18 \times 10^3$

$C_r = 1$

$(t_f - t_c) = 60^oC$

$E = 240\text{ V}$

$I = 5\text{A}$

$\eta = 80\%$

$t = ?$

$$\eta = \frac{M\,C_o\,C_r\,(t_f - t_c) \times 100}{EIt}$$

$$\eta\,EIt = m\,C_o\,C_r\,(t_f - t_i)\;100$$

$$t = \frac{m\,C_o\,C_r\,(t_f - t_i)\;100}{\eta\,EI}$$

$$= \frac{3 \times 4.18 \times 10^3 \times 60 \times 100}{80 \times 240 \times 5}$$

$$= 784\text{ s}$$

$$= 13\text{ min } 4\text{s}$$

Equations in this chapter

(1) $H = m\,C\,t_c$

(2) $H = m\,C_o\,C_r\,(t_f - t_i)$

(3) $\text{Input} = E\,I\,t$

(4) $\eta = \dfrac{m\,C_o\,C_r\,(t_f - t_i)}{E\,I\,t} \times \dfrac{100}{1}$

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(1) Calculate the energy required to raise the temperature of 2 kg of copper from 20^oC to 80^oC.

(2) Five thousand kilojoules of heat are absorbed by a mass of aluminium when its temperature is raised through 75^oC. Calculate the mass of the aluminium.

(3) An electric jug having an efficiency of 90% takes six minutes to boil from an initial temperature of 20^oC. If the jug draws 5 amperes from a 240 volt supply calculate the quantity of water in the jug.

(4) An electrical heating process draws 10 amperes from a 240 volt for 5 minutes as it raises the temperature of 15 kg of copper through 100^oC. Calculate the efficiency of the heating system.

(5) Determine the power rating of an electrical urn which raises the temperature of 5 litres of water from 20^oC to boiling point in 10 minutes if the urn is 80% efficient.